GREENHOUSE GAS EMISSIONS IN COLD CHAIN AGRICULTURAL LOGISTICS

Nilubon Chonsawat 1, Natapol Thongplew 2, Channarong Puchongkawarin 3, 4 Poti Chaopaisarn,* Ganda Boonsothonsatit 5

1 Department of Agricultural Economy and Development,
Faculty of Agriculture, Chiang Mai University; nilubon.chon@cmu.ac.th

2 Department of Biological Science,
Faculty of Science, Ubon Ratchathani University; natapol.t@ubu.ac.th

3 Department of Chemical Engineering,
Faculty of Engineering, Ubon Ratchathani University; channarong.p@ubu.ac.th

4 Supply Chain and Engineering Management Research Unit, Department of Industrial Engineering,
Faculty of Engineering, Chiang Mai University; poti@eng.cmu.ac.th

5 Graduate School of Management and Innovation,
King Mongkut's University of technology Thonburi
**Corresponding: kanda.boo@kmutt.ac.th*

Abstract

Purpose - The transportation sector contributes to global greenhouse gas (GHG) emissions, accounting for approximately 26%. Considering this environmental challenge, this research aims to compare GHG emissions across three transportation modes in cold chain logistics of agricultural products.

Design/methodology/approach - The study quantified the environmental impact for each mode — air, road, and rail, using LCA methodology with a case study from northern to southern Thailand over 1,628 kilometres in cold chain logistics of agricultural products.

Findings - The results show that air transport, which is the fastest transportation mode, is also the most emission-intensive at 0.8191 kgCO2-eq/tonne-km, primarily due to high fuel requirements. Road transport offers more flexibility and is widely used, emitting 0.1591 kgCO2-eq/tonne-km. Rail transport is not widely used in Thailand, but it emerges as the most sustainable route, producing only 0.0817 kgCO2-eq/tonne-km.

Research limitations/implications - The analysis did not account for emissions due to factors such as traffic congestion, frequent stopping and starting of vehicles, or other operational delays. It also does not include greenhouse gas emissions related to support activities during loading and unloading.

Practical implications - Research findings underscore the potential for significant emission reductions in cold chain logistics through prioritizing rail transport, highlighting the importance of sustainable transportation in the agriculture sector and mitigating the environmental impact. Despite high initial construction costs, rail transport had lower overall emissions due to its longevity and energy efficiency.

Originality/value - This study provides a comprehensive comparison of GHG emissions across different transportation modes specifically for cold chain agricultural logistics in Thailand, contributing to sustainable transportation decision-making in the agriculture sector.

Keywords – agricultural products, cold chain logistics, greenhouse gas emissions, life cycle assessment, transportation modes.

Introduction

Developing cold chain logistics is a crucial strategy for enhancing logistics and supply chain management in the agricultural and perishable sectors (Han *et al.*, 2021). It aims to promote the development of operations, reduce losses, and ensure traceability in logistics activity. Nevertheless, transportation plays a significant role in climate change, contributing up to 26% of global greenhouse gas emissions (Rivera *et al.*, 2022).

Reducing transportation emissions is essential for reducing the impacts of climate change and achieving sustainability (Zhang and Fujimori, 2020). Assessing emissions from various activities and processes within transportation is important for developing effective strategies for reducing environmental effects. This approach focuses on creating economic and social value while reducing environmental impact by maximizing resource efficiency (Ciliberto *et al.*, 2021). By considering the greenhouse gas emissions, Life Cycle Assessment (LCA) is an important technique to evaluate the environmental impacts of a product or service, from raw material, manufacturing, and transportation to product usage and disposal (ISO, 2022; Saxe and Kasraian, 2020). The development of circular economy-based cold chain logistics also presents a promising opportunity to address these challenges (Chester and Horvath, 2009).

In 2021, the demand for vegetables and fruits from northern Thailand in the southern region reached a significant 193 tonnes, equivalent to 96 20-foot containers. This volume was transported through air and road. While air transport offers speed, it comes at a high cost financially and environmentally. Though more flexible, road transportation contributes substantially to greenhouse gas (GHG) emissions and traffic congestion. Recognizing these challenges, the Thai government has initiated support for rail transportation, aiming to diversify and optimize the nation's logistics infrastructure.

The pressing need to implement circular economy principles in cold chain logistics for agricultural products necessitates a comprehensive evaluation of transportation modes. Thus, this research aims to conduct a comparative analysis of greenhouse gas emissions across rail, road, and air transport within cold chain logistics, transporting agricultural products from northern to southern Thailand, a total distance of 1,628 kilometres, by employing LCA methodology. This result is crucial for informing policy decisions and industry practices to support Thailand's growing demand for agricultural products while minimizing environmental impact.

The structure of this research is that the following research will proceed with a literature review, Life Cycle Assessment (LCA) application in cold chain logistics and greenhouse gas emissions. The third section outlines the research methodology, and the fourth section presents the results. Finally, the last section will present the research conclusion and the limitations.

Literature review

This section is a literature review that aims to synthesize current research on cold chain logistics, focusing on comparing different transportation modes using the LCA principle.

Cold chain logistics and sustainability

Generally, cold chain logistics ensures that sensitive products are transported under controlled temperatures (Pajic *et al.*, 2024) to maintain optimal temperature conditions for perishable products throughout the supply chain. That plays a crucial role in the global economy, ensuring the safe transportation of perishable goods (Titlo *et al.*, 2024). However, the energy-intensive nature of temperature-controlled supply chains contributes significantly to GHG emissions, raising concerns about environmental sustainability. According to Ndraha *et al.* (2020), efficient cold chain management can significantly reduce waste, lower costs, and improve product traceability. However, the energy-intensive nature of cold chain operations poses environmental challenges.

Hazen *et al.* (2021) emphasized the potential for circular economy models to reduce environmental impacts in logistics. Their study highlighted how integrating principles of resource reuse, remanufacturing, and recycling can minimize waste in supply chains. This approach aligns with broader sustainability goals and offers a framework for improving the environmental performance of supply chain in developed and developing nations. According to Banihashemi *et al.* (2023), emphasized the potential for circular economy models to reduce environmental impacts in digital transformation perspective.

LCA in cold chain logistics and transportation mode

LCA has emerged as a tool for evaluating the environmental impacts of cold chain logistics. LCA is a methodological framework for assessing the environmental impacts of product systems through circular economy principles, from raw material extraction through production, use, and disposal to improved circularity and resulting environmental impacts (Luthin *et al.*, 2024).

In the context of cold chain logistics, Dong *et al.* (2022) outline LCA approaches, including process-based, economic input-output. This establishes the context and aims to address the identified gap by using a hybrid LCA approach to estimate greenhouse gas emissions of cold warehouses in China over 40 years. Shen et al. (Shen *et al.*, 2023) conducted an LCA-based energy analysis on cold food storage using strawberries as a case study. They highlighted the significant energy consumption in warehousing and suggested optimization strategies for reducing energy use and emissions.

A key focus of recent research has been comparing different transportation modes in cold chain logistics. Trevisan and Bordignon (2020) conducted an exploratory LCA comparing CO2 and GHG emissions across air, road, and rail transport. Their findings reinforced the environmental benefits of rail transport over road and air. Lee *et al.* (2008) further analyzed the environmental loads of gravel and concrete rail tracks using LCA.

This literature review highlights research on sustainable cold chain logistics and uses LCA methodologies to compare transportation modes and identify critical energy consumption and emissions points. As mentioned, this research consistently emphasizes the environmental impacts of different transportation modes in cold chain logistics, particularly in regions like Thailand, where the sector plays a vital role in economic development and food security.

Research methodology

This study aims to compare the greenhouse gas emissions of different transportation modes used to transport agricultural products from northern to southern Thailand. The methodology employs an LCA approach, focusing on three transportation modes.

Data collection

The functional unit for this study is defined as the transportation of 1 tonne of product over a distance of 1 kilometre (a tonne-kilometre, tkm). This unit allows for standardized comparison across different transportation modes. The system boundary encompasses the entire transportation process from the point of origin in northern Thailand to the final destination (customer) in southern Thailand, covering a distance of approximately 1,628 kilometres. Three primary transportation modes are considered in this study: air, road, and rail. Data for this study is collected from both primary and secondary sources. First, the primary data is obtained through interviews with relevant stakeholders, including:

- Consolidators and distributors of agriculture in northern Thailand
- Representatives from the State Railway of Thailand
- Logistics service providers

These interviews aim to gather information on transportation routes, vehicle types, load factors, and, where possible, fuel consumption data. Then, the secondary data is sourced from:

- The Ecoinvent database (Wernet *et al.*, 2016)
- The Intergovernmental Panel on Climate Change (IPCC) 2013 report (Secretariat, 2013)

GHG emissions calculation

Given that the transportation of agricultural products is often handled by third-party service providers, direct access to energy consumption or fuel usage data might not be available. In such cases, this study employs the activity-based calculation method to estimate greenhouse gas emissions, commonly used in life cycle assessment studies. The activity-based calculation method follows the general formula (1):

$$\text{GHG Emissions} = \text{activity data} \times \text{emission factor} \quad (1)$$

Where, *activity data* represents the tonne-kilometres of goods transported and Emission Factor is derived from the Ecoinvent database (Wernet *et al.*, 2016)and IPCC 2013 report (Secretariat, 2013).

Data analysis and comparison

The calculated GHG emissions for each transportation mode (railway, road, and air) will be compared to identify the most sustainable practices for transporting agricultural products from northern to southern Thailand. This comparison will consider factors such as distance, load capacity, and energy efficiency of each mode. The quantity of transported goods affects the amount of greenhouse gas emissions. This research also considers transportation volumes ranging from 100 to 200 tonnes to study the impact of greenhouse gas emissions when changes in shipment volume occur.

The results of this research will contribute to the knowledge of cold chain logistics. They may inform policy decisions to reduce the environmental impact of agricultural product transportation in Thailand.

<u>Result</u>

Greenhouse gas emission by mode of transport

Air transport is the primary method used by agricultural distributors in northern Thailand. The process begins with loading products into boxes and transporting by a 4-wheel refrigerated truck to Chiang Mai International Airport in northern Thailand. Here, the products are transferred to an aircraft equipped with cold storage, transporting products to the destination airport at Hat Yai International Airport, southern Thailand. Upon arrival at the destination, customers pick up agricultural products from the warehouse. The transportation details and emission factors for air transport are summarized, see Table 1.

Emission factors	Quantity	Unit
4-wheel refrigerated truck		
Load weight	290	kg
Fuel consumption rate	4.50	km/l
Total transportation distance	32	km
Fuel consumption	7.11	liters
Cardboard boxes	35	boxes
Aircraft Airbus A320		
Load weight	290	kg
Fuel consumption (Boonlasette and Worrapon, 2023)	7,400	liters

Table 3: Emission factors of agricultural transport from northern to southern Thailand by air

Road transport is used for special events, such as exhibitions, and employs a logistics provider. Products are packed in reusable plastic baskets and transported by a 10-wheel refrigerated truck from northern Thailand's distributors in agriculture to a Hat Yai, Songkhla distribution center in southern Thailand. There are no return shipments from the south to Chiang Mai in northern Thailand; only empty baskets are returned. The transportation details and emission factors for road transport are summarized in Table 2.

Transportation Details	Quantity	Unit
10-wheel refrigerated truck		
Load weight	3,250	kg
Fuel consumption rate	3.30	km/l
Plastic baskets	324	baskets

Table 4: Emission factors of agricultural transport from northern to southern Thailand by road

Rail transport is a new transportation model in this research. The process begins with loading products into reefer containers and transporting them by a crane truck from northern Thailand's distributors to Lamphun Railway Station. Then, the containers are transferred by rail using a reach stacker and transported from Lamphun Railway Station to Ban Phachi Junction Railway Station and Bang Sue Grand Station in Bangkok, then to the destination in Bang Klam Station in Songkhla, southern Thailand. At Bang Klam Station, the containers are unloaded using a reach stacker, and customers pick up the products with 10-wheel trucks. The transportation details and emission factors for rail transport are summarized, see Table 3.

Transportation details	Quantity	Unit
Crane truck		
Load weight	7,956	kg
Plastic baskets weight	1,734	kg
Fuel consumption rate (loaded)	2.8	km/l

Transportation details	Quantity	Unit
Fuel consumption rate (unloaded)	3.2	km/l
Transportation distance	26	km
Reach stacker		
Fuel consumption (Rani, 2010)	19	liters/hr
Train		
Fuel consumption rate (State Railway of Thailand, 2006)	0.25	km/l
Transportation distance	1,648	km
Refrigerated container		
Size	20	feet
Container weight	2,430	kg
Cooling equipment weight	465	kg
Generator weight	1,157	kg
Power consumption	2	kWh
Generator power	5	VA
Generator fuel consumption	1.1	liters/hr
Insulation material	Polyurethane	
Refrigerant	R407C	
Refrigerant amount	3	kg

Table 5: Emission factors of agricultural transport from northern to southern Thailand by rail

The greenhouse gas emissions for each transportation mode are calculated based on IPCC guidelines (Secretariat, 2013), using activity data from each mode and emission factors from various processes. Emissions are expressed in kg CO2 equivalent (kgCO2tkm). The coefficients for greenhouse gas emissions of vehicles and refrigerated containers are summarized, see Table 4.

Transport type	CO2 emission coefficient	Unit
Air Transport		
4-wheel refrigerated truck	0.488	kgCO2tkm
Refrigerated aircraft	0.761	kgCO2tkm
4-wheel truck (unloaded)	0.3345	kgCO2tkm
Cardboard box	0.57	kgCO2/ box
Road Transport		
10-wheel refrigerated truck	0.29	kgCO2tkm
10-wheel truck (50% load)	0.0852	kgCO2tkm
Plastic basket	0.2	kgCO2/basket
Rail Transport		
10-wheel truck	0.0533	kgCO2tkm
10-wheel truck (unloaded)	0.59	kgCO2tkm
Diesel engine operation	0.0421	kgCO2hr
Diesel train engine	0.0552	kgCO2tkm
20-foot refrigerated container	0.00693	kgCO2km /day
20-foot container	0.00013	kgCO2km /day

Table 6: Greenhouse gas emission coefficients for transport modes (IPCC).

Greenhouse gas emissions analysis
The greenhouse gas emissions analysis reveals significant differences among transportation modes. Rail transport is the most environmentally friendly option, emitting the most minor greenhouse gases at 0.0817 kgCO2-eq/tonne-km. Road transport follows with moderate emissions of 0.1591 kgCO2-eq/tonne-km. Air transport is the highest emitter at 0.8191 kgCO2-eq/tonne-km. These findings are visually represented in Fig. 1, which compares the emissions across the three modes.

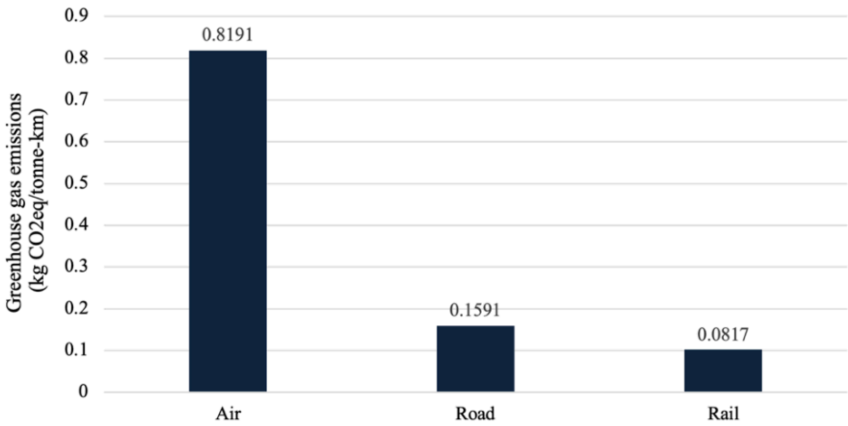

Fig. 2. Greenhouse gas emissions for different transportation modes

The stark contrast is evident in the data. Air transport produces 5.15 times more emissions than road transport and exactly 10.03 times more than rail. While the fastest, air transport is also the most energy-intensive and emissions-heavy mode. The higher emissions from air transport can be attributed to two main factors: the substantial fuel required for flight and the higher impact of emissions released at altitude. This is consistent with findings from Facanha and Horvath (2007) concluded that air cargo had significantly higher CO2 emissions per ton-mile than rail transport in their life-cycle analysis of freight transportation modes.

Road transport remains a dominant mode for cold chain logistics due to its flexibility and extensive infrastructure. However, it is also a significant contributor to GHG emissions. An environmental assessment of road transport revealed considerable energy consumption and emissions, emphasizing the need for more sustainable practices in this sector. In contrast, rail transport demonstrates the lowest emissions due to its energy efficiency compared to road and air transport. Rossi et al. (Rossi *et al.*, 2021) emphasize that intermodal rail-road transportation can significantly reduce carbon dioxide emissions, making it a viable alternative for perishable food logistics. These findings align with previous research, which conducted life cycle assessments of freight transport modes. Such studies consistently showed rail transport had lower environmental impacts, including global warming potential, than road and air transport. This efficiency can be attributed to rail's ability to move large quantities of goods with relatively lower energy consumption

Conclusion

Cold chain logistics is critical in maintaining product quality and reducing spoilage throughout the supply chain. However, the significant energy of this sector is significant, and it substantially contributes to greenhouse gas emissions. This study employed LCA methodology to evaluate the environmental impacts of different transportation modes within cold chain logistics for agricultural products in Thailand. It compared rail, road, and air transport regarding their GHG emissions.

A comparative study on the GHG emissions of air, road, and rail transport highlighted that air transport emissions were significantly higher than those of rail and road, making it the least sustainable option among the three. It is important to note that road transport remains dominant in cold chain logistics due to its flexibility and existing infrastructure. However, it is also a significant contributor to GHG emissions. Then, rail transport generally has lower emissions due to its energy efficiency compared to road and air transport, as it can transport large quantities of goods.

In conclusion, this study contributes to cold chain management for agricultural products. As the global focus on sustainability intensifies, the insights provided by this research will be crucial in shaping the future of environmentally responsible cold chain logistics in Thailand and potentially in other regions with similar logistical challenges. The insights from this study provide a foundation for understanding the potential benefits of changing to rail transport for reducing greenhouse gas emissions in agricultural product transportation.

It is important to note the limitations of this research. The analysis did not account for emissions due to factors such as traffic congestion, frequent vehicle stopping and starting, or other operational delays. It also does not include greenhouse gas emissions related to support activities during loading and unloading.

Future research should focus on developing more comprehensive LCA models that incorporate detailed operational data. There is also a need to explore innovative technologies for improving energy efficiency in cold chain logistics, particularly for perishable products.

Acknowledgements
This research project is supported by King Mongkut's University of Technology Thonburi (KMUTT), Thailand Science Research and Innovation (TSRI), and National Science, Research and Innovation Fund (NSRF) Fiscal year 2024.

References

- Banihashemi, S., Meskin, S., Sheikhkhoshkar, M., Mohandes, S. R., Hajirasouli, A., and LeNguyen, K. (2023), "Circular economy in construction: The digital transformation perspective". Cleaner Engineering and Technology,pp. 100715.
- Boonlasette, M., and Worrapon, W. (2023), "Developing a Model Forecasting Extra Fuel for Airbus A320-200 Landing at Suvarnabhumi Airport: a case study of Thai Smile Airways". Sripatum Review of Science and Technology,Vol. 15,pp. 26-40.
- Chester, M. V., and Horvath, A. (2009), "Environmental assessment of passenger transportation should include infrastructure and supply chains". Environmental research letters,Vol. 4 No.2,pp. 024008.
- Ciliberto, C., Szopik-Depczyńska, K., Tarczyńska-Łuniewska, M., Ruggieri, A., and Ioppolo, G. (2021), "Enabling the Circular Economy transition: A sustainable lean manufacturing recipe for Industry 4.0". Business Strategy and the Environment,Vol. 30 No.7,pp. 3255-3272.
- Dong, Y., Miller, S. A., and Keoleian, G. A. (2022), "Estimating the greenhouse gas emissions of cold chain infrastructure in China from 2021 to 2060". Sustainable production and consumption,Vol. 31,pp. 546-556.
- Facanha, C., and Horvath, A. (2007), "Evaluation of life-cycle air emission factors of freight transportation". Environmental science & technology,Vol. 41 No.20,pp. 7138-7144.
- Han, J.-W., Zuo, M., Zhu, W.-Y., Zuo, J.-H., Lü, E.-L., and Yang, X.-T. (2021), "A comprehensive review of cold chain logistics for fresh agricultural products: Current status, challenges, and future trends". Trends in Food Science & Technology,Vol. 109,pp. 536-551.
- Hazen, B. T., Russo, I., Confente, I., and Pellathy, D. (2021), "Supply chain management for circular economy: conceptual framework and research agenda". The International Journal of Logistics Management,Vol. 32 No.2,pp. 510-537.
- ISO. (2022), "SO 14040:2006 Environmental management - Life cycle assessment - Principles and framework.".
- Lee, C., Lee, J., and Kim, Y. (2008), "Comparison of environmental loads with rail track systems using simplified life cycle assessment (LCA)". WIT transactions on the Built Environment,Vol. 101,pp. 367-372.
- Luthin, A., Traverso, M., and Crawford, R. H. (2024), "Circular life cycle sustainability assessment: An integrated framework". Journal of Industrial Ecology,Vol. 28 No.1,pp. 41-58.
- Ndraha, N., Vlajic, J., Chang, C.-C., and Hsiao, H.-I. (2020). Challenges with food waste management in the food cold chains. In *Food industry wastes* (pp. 467-483): Elsevier.
- Pajic, V., Andrejic, M., and Chatterjee, P. (2024), "Enhancing cold chain logistics: A framework for advanced temperature monitoring in transportation and storage". Mechatron. Intell Transp. Syst,Vol. 3 No.1,pp. 16-30.
- Rani, J. (2010), "Tariff authority for major ports ".
- Rivera, A., Movalia, S., Pit, H., and Larsen, K. (2022), "Global Greenhouse Gas Emissions: 1990-2020 and Preliminary 2021 Estimates". Rhodium Group,Vol. 19.
- Rossi, T., Pozzi, R., Pirovano, G., Cigolini, R., and Pero, M. (2021), "A new logistics model for increasing economic sustainability of perishable food supply chains through intermodal transportation". International Journal of Logistics Research and Applications,Vol. 24 No.4,pp. 346-363.

- Saxe, S., and Kasraian, D. (2020), “Rethinking environmental LCA life stages for transport infrastructure to facilitate holistic assessment”. Journal of Industrial Ecology,Vol. 24 No.5,pp. 1031-1046.
- Secretariat, I. (2013), “Intergovernmental Panel on Climate Change (IPCC)”. Retrieved Δεκέμβριος,Vol. 3,pp. 2015.
- Shen, K., Logozzo, P., Sawant, M., Yuan, B., Bolis, N., Kim, Y., and Li, B. (2023), “Life-cycle assessment based energy consumption analysis for cold food storage facilities”. Procedia CIRP,Vol. 116,pp. 624-629.
- State Railway of Thailand. (2006), “State Railway of Thailand increases oil surcharge for commercial class passenger ”.
- Titlo, N., Sopadang, A., and Chonsawat, N. (2024), “Performance measurement of cold chain exporting: fresh longan exporting”. International Journal of Logistics Systems and Management,Vol. 48 No.3,pp. 414-436.
- Trevisan, L., and Bordignon, M. (2020), “Screening Life Cycle Assessment to compare CO2 and Greenhouse Gases emissions of air, road, and rail transport: An exploratory study”. Procedia CIRP,Vol. 90,pp. 303-309.
- Wernet, G., Bauer, C., Steubing, B., Reinhard, J., Moreno-Ruiz, E., and Weidema, B. (2016), “The ecoinvent database version 3 (part I): overview and methodology”. The International Journal of Life Cycle Assessment,Vol. 21,pp. 1218-1230.
- Zhang, R., and Fujimori, S. (2020), “The role of transport electrification in global climate change mitigation scenarios”. Environmental research letters,Vol. 15 No.3,pp. 034019.